A 1.5 TeV Injector for the LHC

(the early days)

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- Motivation for a 2nd ring.
- Injector Design Constraints & Concept.
- Magnets:
  - Main Ring Magnets
  - Special Fast Magnets
- Lattice Design (partial):
  - Arcs & Dispersion Suppressers
  - IR1 & 5 High Luminosity Straights
  - Magnet count for IR1 & 5
- Continuing Studies

Contributed courtesy of Henryk Piekarz (TD/Fermilab), aided & abetted by Steve Hayes (power supplies), and V. Kashikhin (fast magnets).

J.A.J

Motivation for the LHCI:

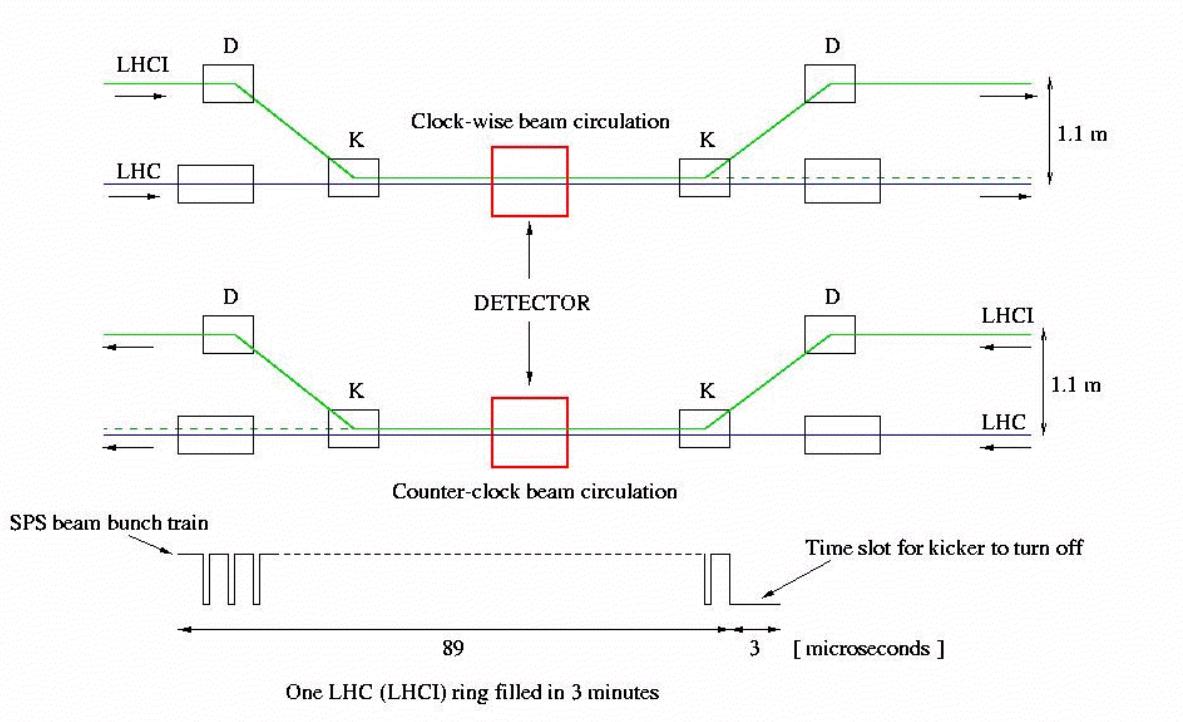
- The LHC magnets are reputed to have unsatisfactory field quality at the 450 GeV SPS injection energy.
- Possible options are: (a) build a new SPS ring to boost the energy to 1 TeV or better, and; (b) build a new injector within the LHC tunnel to accelerate the 450 GeV beams to 1.5 TeV for transfer to the LHC.
- Advantages to option (b) [originally suggested by Lucio Rossi of CERN (9/05) & subsequently pursued by Henryk Piekarz] are:

  (i) the ring would be installed during scheduled LHC downtime — no HEP interruptions, and;

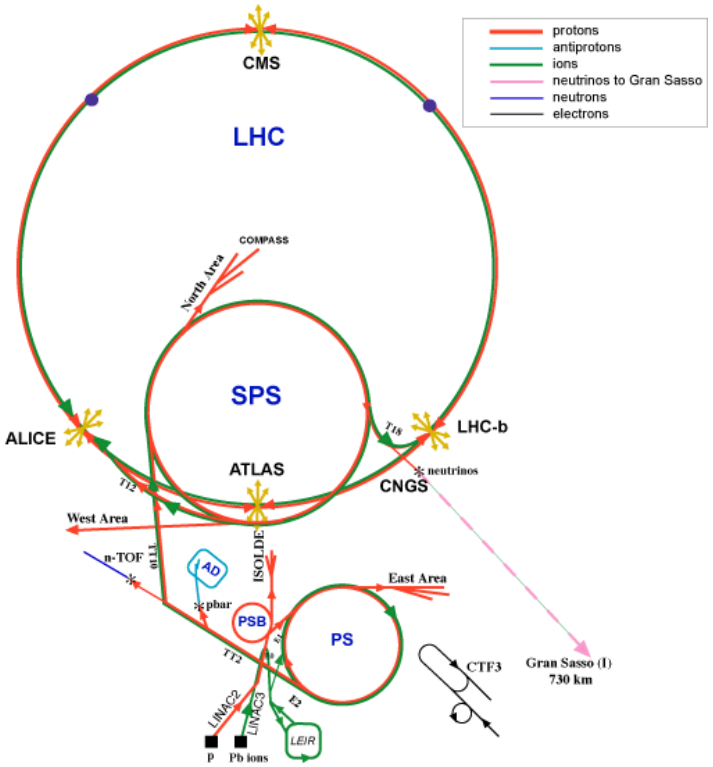
  (ii) with little, or no civil construction the price is reasonably cheap — ~$150 million (less than MI, for example).

Design Constraints & Concept:

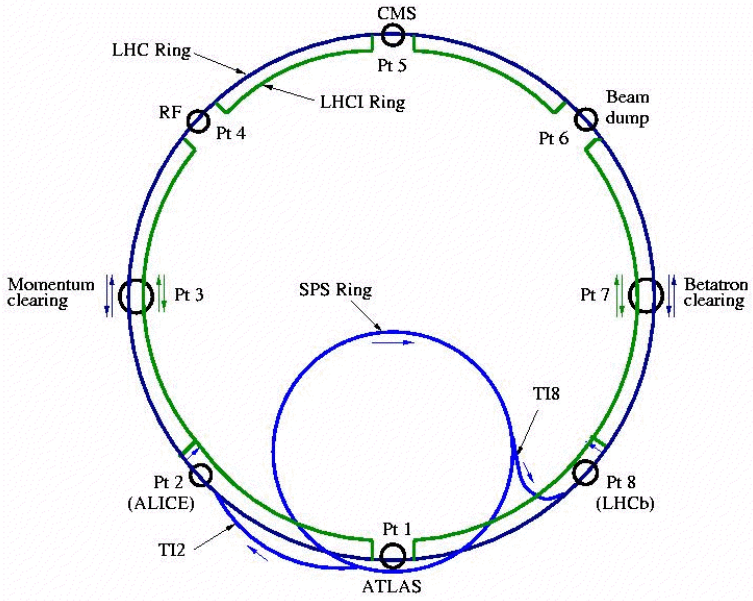
- The LHCI would be installed above the LHC in the LHC tunnel without major modifications ⇒ at a minimum the LHCI & LHC must share common beampipes through the detectors at IR1 & IR5 (Atlas & CMS).



- The magnet strings common to LHCI & LHC must be able to turn on/off in 3 μsec (the separation between the head & tail of the bunch train).

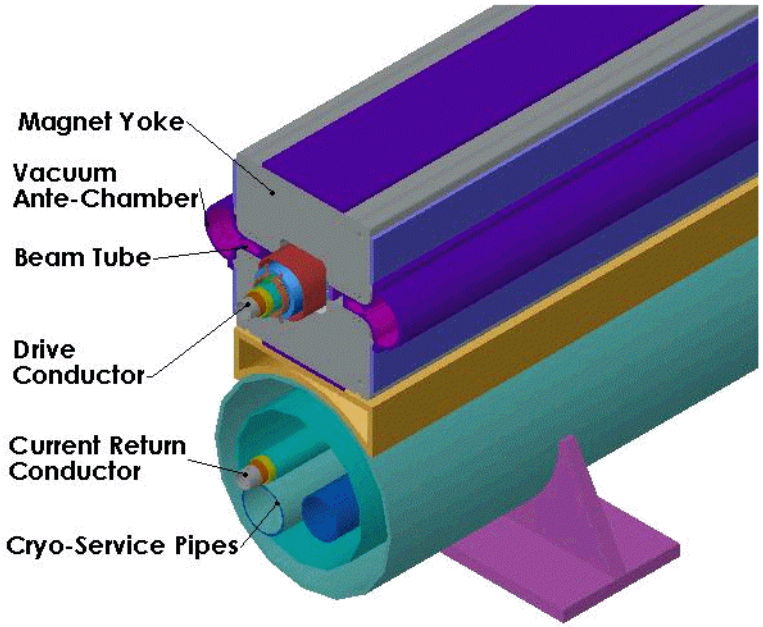


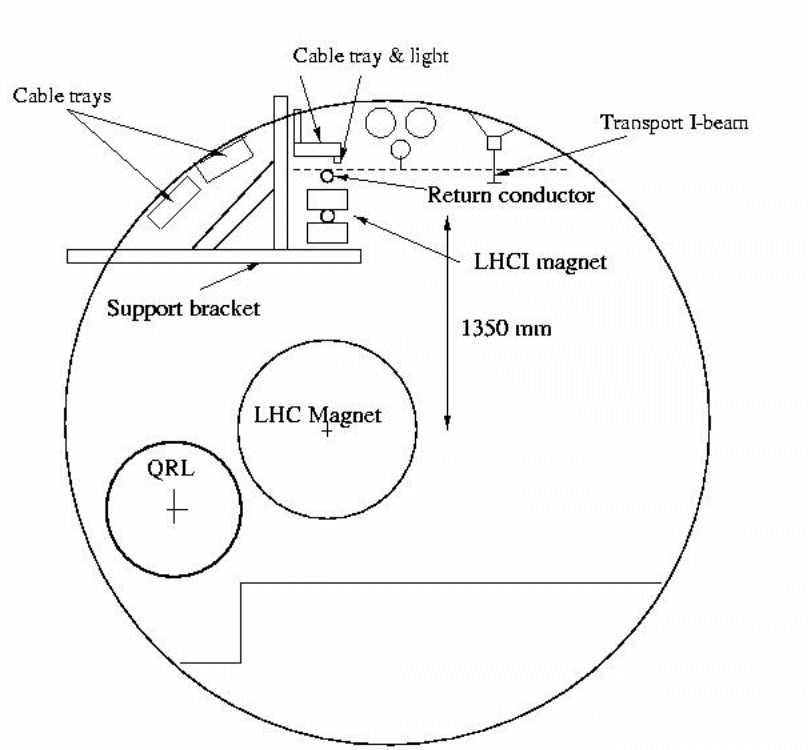
- Injection would continue to occur at IR's 2 & 8, with immediate transfer to the LHCI for acceleration to 1.5 TeV (details need to be worked out).



- Momentum & betatron scraping at IR's 3 & 7 can not be used by the LHCI.
- It is *hoped* that the RF at IR4 can be used (but seems unlikely at this time).
- It is *hoped* that the dump at IR6 can be used (still needs to be looked at).
- *Alice* & *LHCb* are unknowns.

Low Field VLHC gradient magnets proposed for arcs & dispersion suppressers.

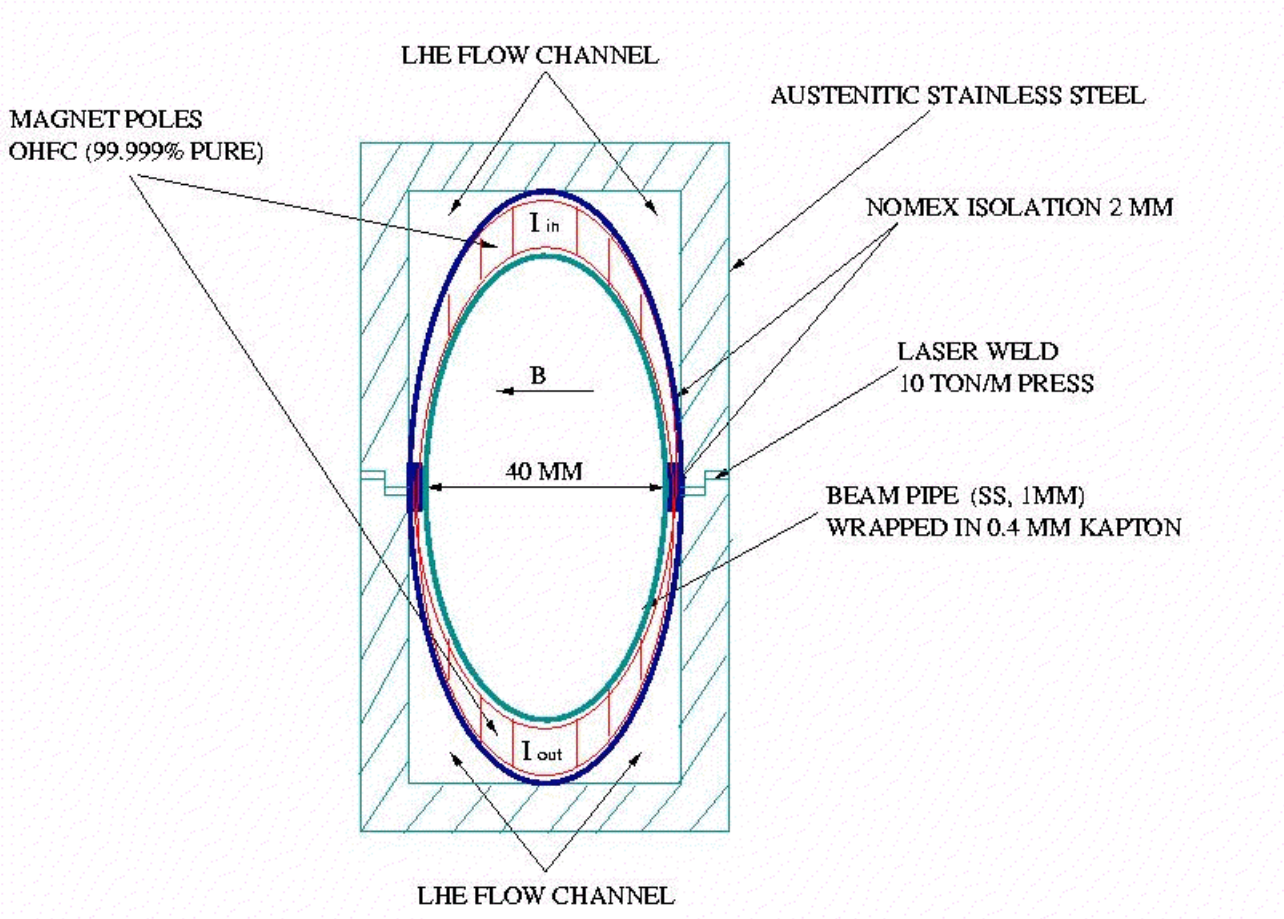




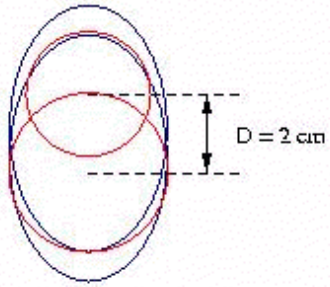
- Small (26 x 24 cm) physical cross-section.
- 1.6 T field at 55 kA.
- 20 mm magnet pole gap.

- The LHCI ring fits easily above the LHC magnets.
- Vertical separation between the LHCI-LHC beams will be 1350 mm.

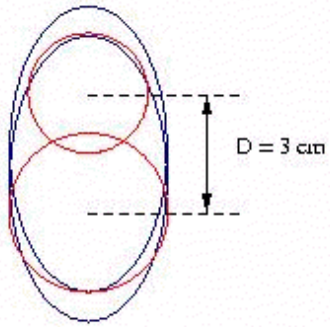
Conceptual Design of Fast Transfer Magnets:



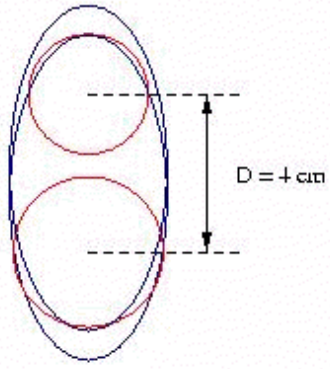
Fields of 4,5 & 6 cm gap Fast Magnets:



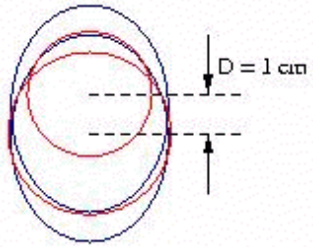
Ef = (3.125 + 2) / (0.75 x 2) = 3.42
S = (3.14 x 2 x 0.75) / 2 = 2.36 cm2
J (1T) = 7.96 x 3.42 = 27.2 kA
I (1T) = 64.2 kA
B (90 kA) = 1.4 T



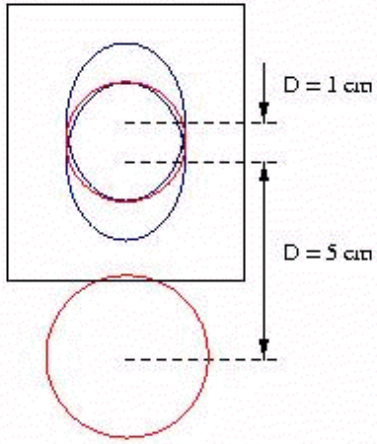
Ef = (3.625 + 2) / (0.75 x 2) = 3.75
S = 2.36 cm2
J (1T) = 7.96 x 3.75 = 29.85 kA
I (1T) = 70.4 kA
B (90 kA) = 1.28 T



Ef = (4.125 + 2) / (0.75 x 2) = 4.08
S 2.36 cm2
J(1T) = 7.96 x 4.08 = 32.5 kA
I (1T) = 76.7 kA
B(90 kA) = 1.17 T



Ef = (2.625 + 2) / (0.75 x 2) = 3.08
S = 2.36 cm2
J (1T) = 7.96 x 3.08 = 24.5 kA
I(1T) = 57.9 kA
B (90 kA) = 1.55 T



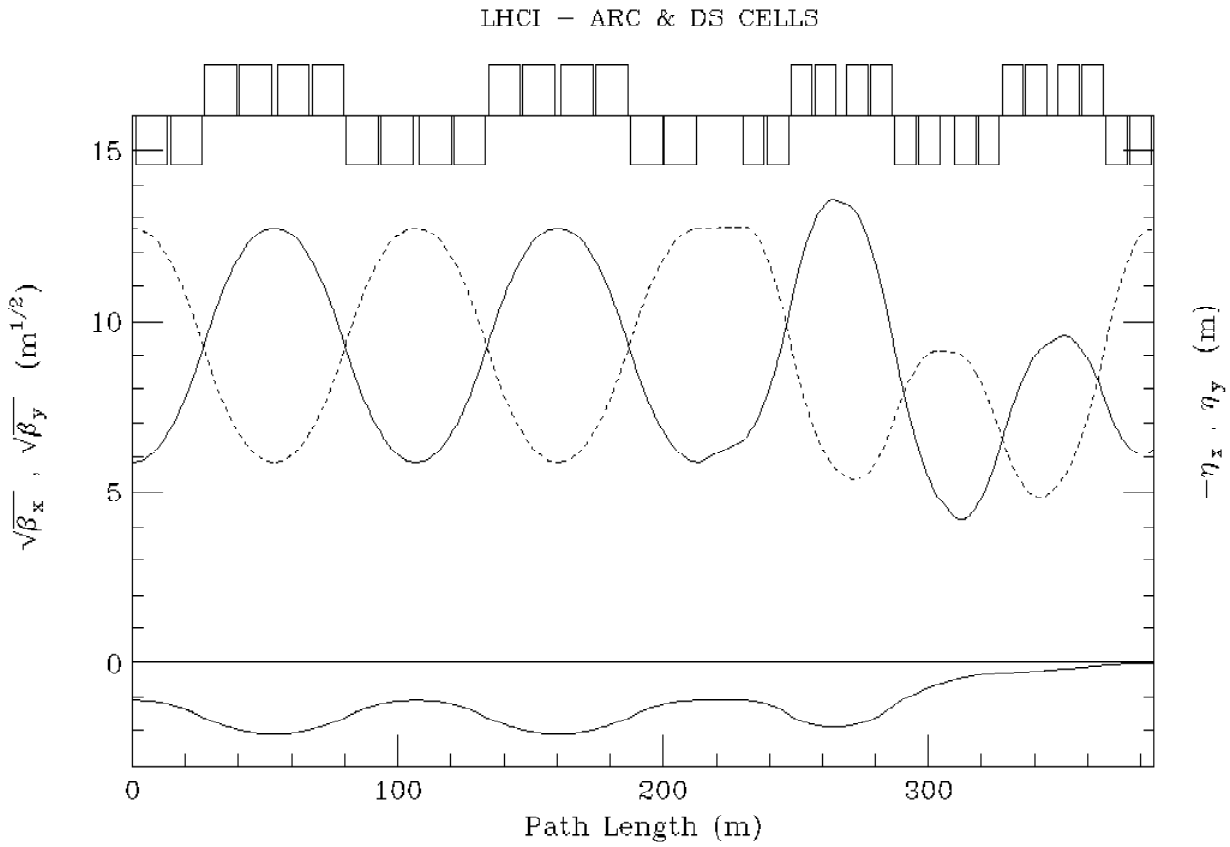
Ef = (2 + 1.5) / (1 x 2) = 1.75
S (3.14 x 1.5 x 1) / 2 = 2.36 cm2
J (1T) = 7.96 x 1.75 = 13.94 kA
I (1T) = 32.9 kA
B (90 kA) = 2.7 T

LHCI Lattice Design

Arc & Generic Dispersion Suppresser Cells:

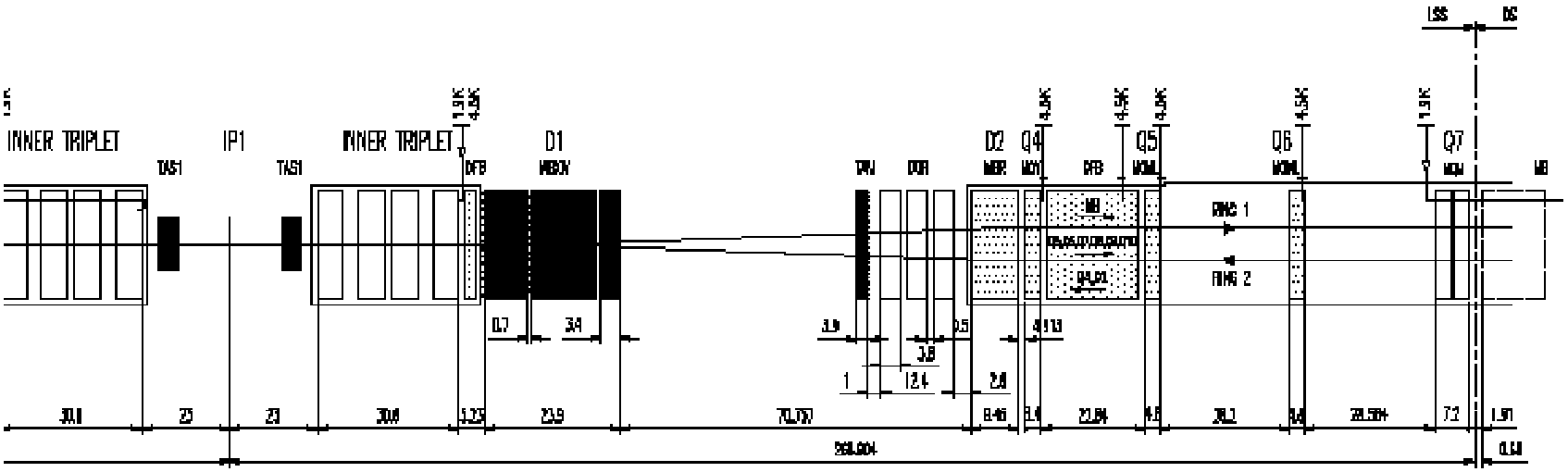
- Constructed from combined function 'transmission line' magnets to replicate LHC optics & match the LHC footprint.
- Dispersion suppressers are similar (sort of) to the Main Injector — $^{2}/_{3}$ the bend & $^{3}/_{4}$ the length of arc cells.

Cell Type	Cell Length (m)	Magnet Types	L_{mag} (m)	# / Cell	B (T)	B' (T/m)
Arc	107	GF / GD	12	8	1.595	4.858
Suppressor	80	GSF / GSD	8	8	1.595	10.112



- β (max) = 162 m
- η (max) = 2.10 m
- Phase advance / cell = 90^{o}

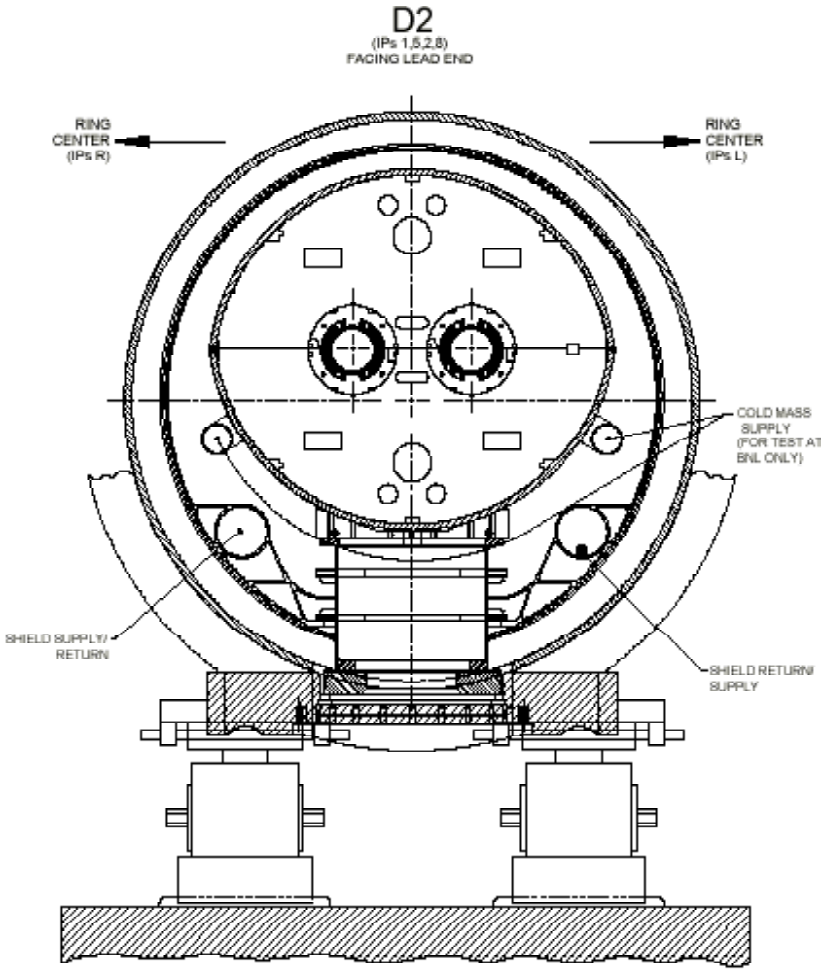
IR1 & IR5 High Luminosity Inserts:



- The 1.35 m altitude change of the LHCI must be accomplished in *very* short distances:

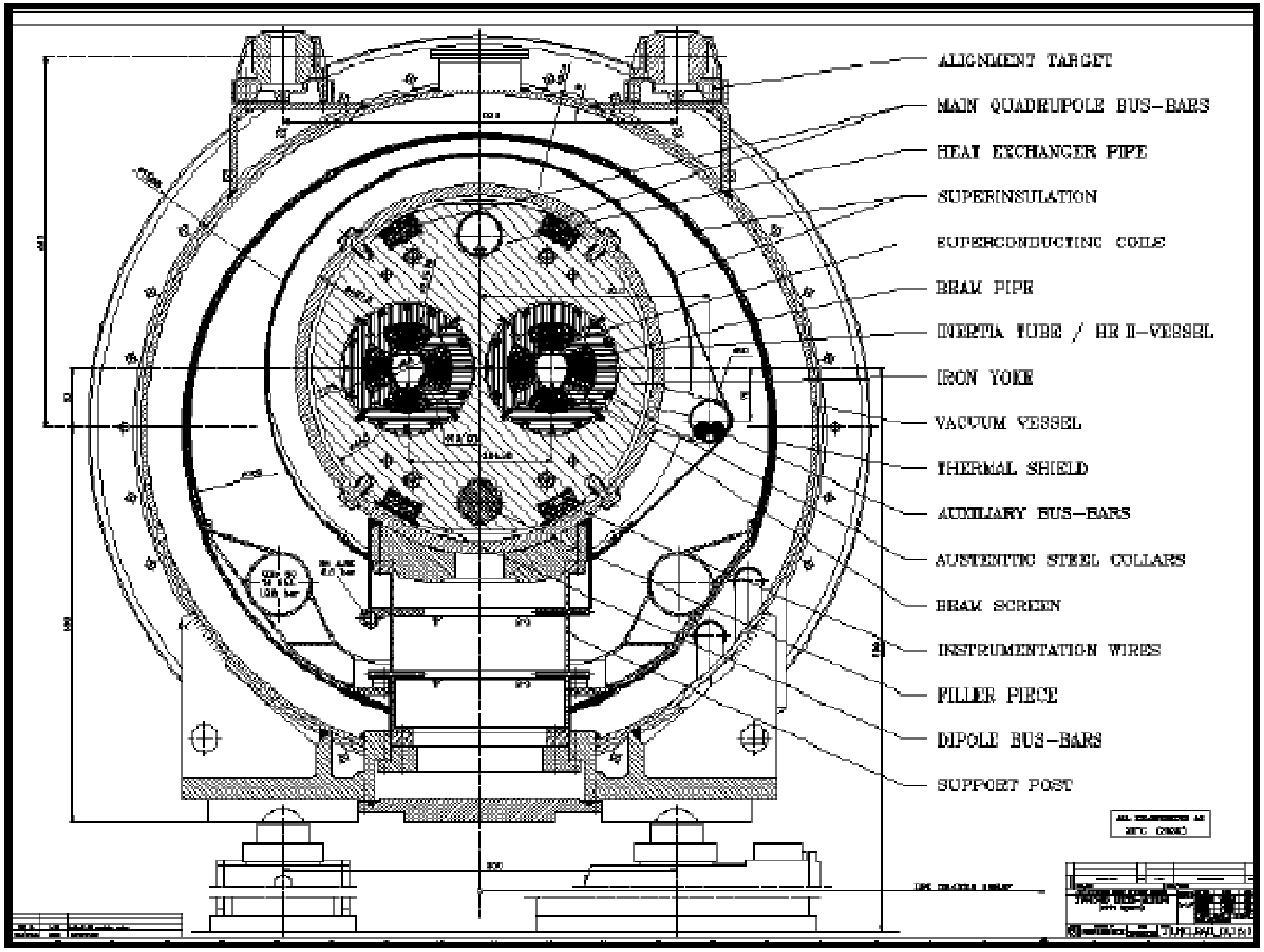
  D1 - D2 ~ 71 m
  Q5 - Q6 ~ 28 m
  Q6 - Q7 ~ 28 m

- Vertical separation of the LHCI from the LHC must start as close to D1 as possible to clear the D2 separation dipoles 71 m downstream. The beams are sufficiently separated to insert fast transfer magnets ~15 m from the face of D1.



D2 Separation Dipole

- LHC magnets are massive -- the beams must rise a minimum of ~480 mm before the LHCI beampipe will clear the D2 (& downstream quadrupoles) cryostat.
- To install quadrupoles in the transfer line above the LHC magnets this elevation change must be significantly more.


ALIGNMENT TARGET
MAIN QUADRUPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
INERTIA TUBE / HE II-VESSEL
IRON YOKE
VACUUM VESSEL
THERMAL SHIELD
AUXILIARY BUS-BARS
AUSTENITIC STEEL COLLARS
BEAM SCREEN
INSTRUMENTATION WIRES
FILLER PIECE
DIPOLE BUS-BARS
SUPPORT POST

Vertical Bends:

- The elevation change to 1.35 m is accomplished in 2 steps — first to 0.675 m above the LHC beam center to clear D2 & the LHC quads, and then another rise to flatten out at 1.35 m by the end of the straight section.
- At the time of the modeling presented here today (obsolete as of yesterday) the vertical bending magnets operated near 100 kA with the following properties:

V1	:	4 cm gap	2.0 T	L = 2 m
V2	:	5 cm gap	2.0 T	L = 2 m
V3	:	6 cm gap	2.0 T	L = 2 m
V4	:	3 cm gap	6.0 T	L = 1 m

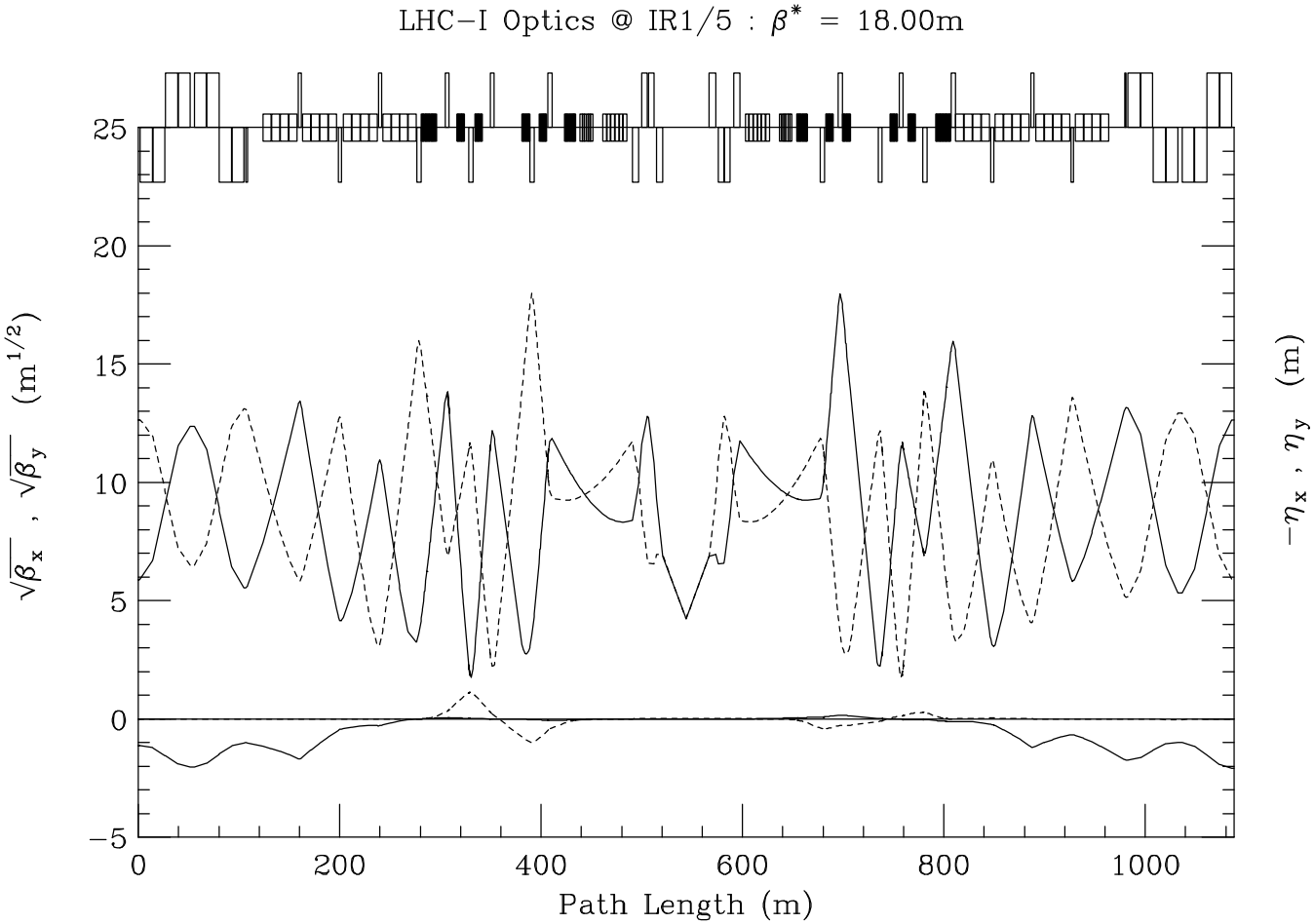
- The initial bending is performed with the fast magnets — 3 with 4 cm gaps, 2 with 5cm, and 1 with 6 cm. Once the beams are well separated vertically the first up bend is completed using 10 of the 1 m long 6.0 T magnets. The remaining 3 bend centers each side of the IP use 14 magnets each, also of the 6.0 T variety.

LHCI Quadrupoles @ IR1 & IR5:

- Quadrupoles in the straight section are powered anti-symmetrically in pairs.
- The dispersion suppressers at these straight comprise separate dipoles & quadrupoles. The quadrupoles are powered individually and are only approximately anti-symmetric.
- Optics of the LHCI are matched to those of the LHC at the face of the separation magnets D1, and therefore to the LHC injection β^*'s of 18.0 m, with horizontal η^* & $\eta'^* = 0$.

- The vertical bends are performed achromatically so vertical dispersion & it's slope are also zero at the IP.

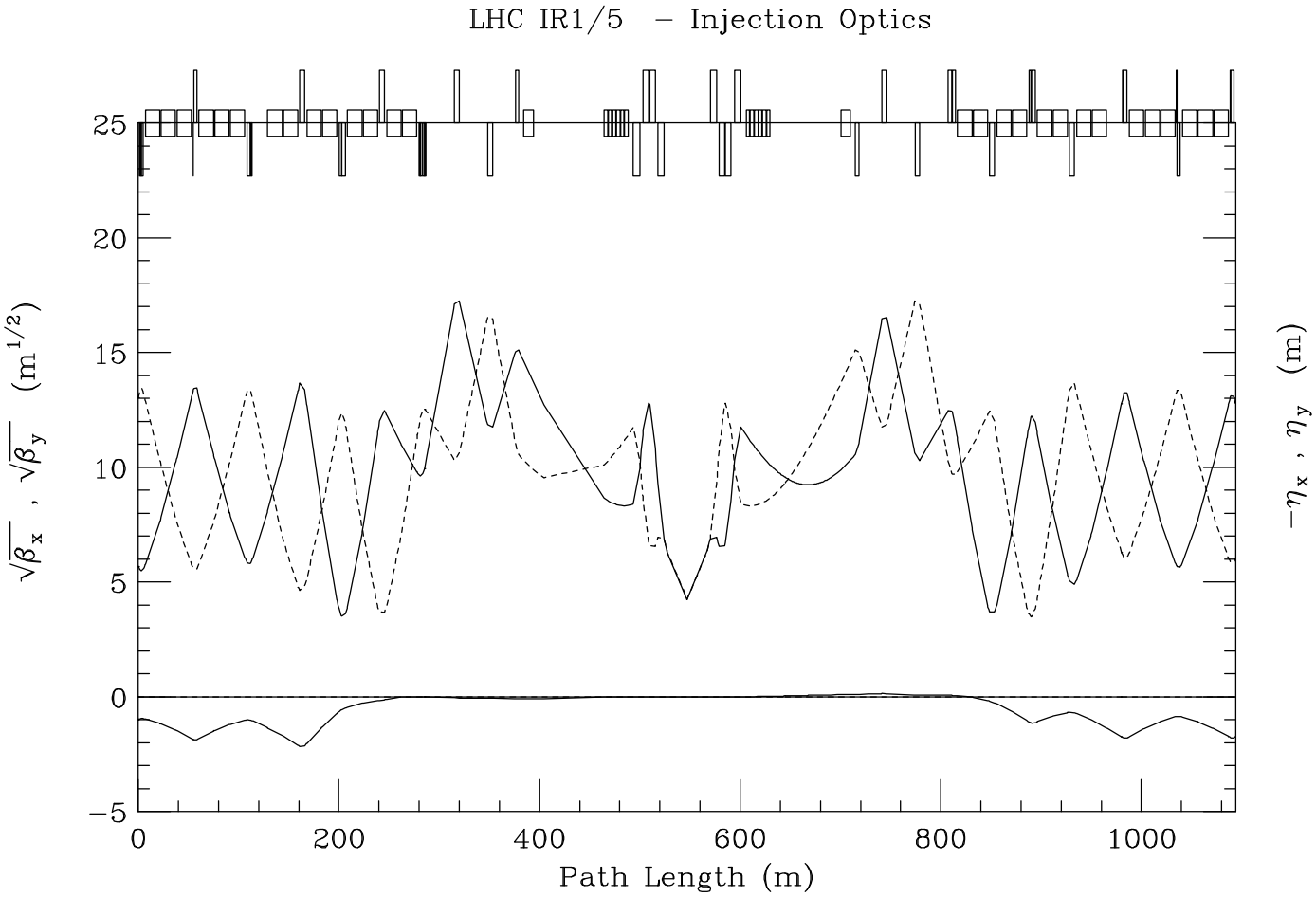
Optics @ IR1 & IR5:



- β* = 18.0 m, with both the horizontal and vertical η* & η'* = 0.
- β (max) = 320 m — comparable to the 300 m in the LHC injection optics.

Quadrupole Parameters @ IR1 & IR5:

Quad	L (mag) (m)	B' (left) (T/m)	B' (right) (T/m)
Q4	4.0	-62.92	62.92
Q5	4.0	68.98	-68.98
Q6	4.0	-97.83	97.83
Q7	4.0	80.88	-80.88
Q8	4.0	-91.25	91.25
Q9	4.0	56.46	-56.46
Q10	3.0	-81.27	80.62
Q11	3.0	68.45	-68.24
Q12	3.0	-58.38	56.39
Q13	1.5	48.02	-39.53



LHC injection optics at IR1 & IR5 for comparison

Updated Fast Magnet Parameters (from H.P. yesterday):

LHCI-LHC Transfer Line Magnet Count

	B [T]	Magnet length [m]	Number of magnets	Drift space [m]	Total Magnet length [m]	Vertical shift [cm]	Total vertical shift [cm]	Beam path [m]	Magnet type
First Bend									
	1.55	0.8	2	0.2	1.8	1	1	1.8	Fast/Normal
	1.40	0.8	2	0.2	1.8	1	2	3.6	"
	1.28	0.7	3	0.3	3.0	1	3	6.6	"
	1.17	0.7	3	0.3	3.0	1	4	9.6	"
				2.4		1	5	12.0	
	LHC-LHCI beam pipe separation								
	2.7	0.9	8	0.8	8.8	7	12	20.8	Slow/Normal
				2.0		2	14	22.7	
	6.0	0.8	10	1.0	9.0	19	33	31.7	Slow/SC
				0.8		1	34	32.5	
Second Bend									
	6.0	0.8	18	1.8	16.2	34	68	48.7	Slow/SC
	LHCI beam passes over the face of D2								
Third Bend									
	6.0	0.8	18	1.8	16.2	34	102	64.9	Slow/SC
				1.0				65.9	
Fourth Bend									
	6.0	0.8	18	1.8	16.2	34	136	82.1	Slow/SC
				1.0				83.1	
	LHCI beam passes over the face of Q5								

All magnets are 2 bore types Total number of magnet assemblies: 6

Continuing (near term) Studies:

- Revise lattice model to accomodate new fast magnet parameters.
- Investigate earlier separation of the beams by horizontal bends at the face of D1.
- Begin looking at IR2 & IR8 for transferring beams to the LHCI.
- Begin looking at the chances of using the LHC RF & beam dump.
- Continue with detailed fast magnet designs & powering options.
- Start design of LHCI quadrupoles.....

.....and so on, *ad infinitum*.

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